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Healthy Gait: Review of Anatomy and Physiology of Knee Joint

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ABSTRACT

The knee joint is a largest, complex synovial joint of a modified hinge variety. There are three articulations. in the knee joint i.e. two between the tibial and femoral condyles and the third with the patella and femur. The main movements occurring on it are flexion and extension on a horizontal axis; but in addition it displays some degree of rotatory movement called locking and unlocking on a vertical axis. It is mainly weight bearing but also helps in locomotion. Man has evolved and has got erect posture and hence advantage of standing on two legs which means weight of the upper part of the body needs to be balanced and carried by the lower limbs. Knee joint along with other structures carries and bears the body weight. This can produce adverse effects on the joint which is subjected to constant stress and thus undergoes wear and tear. This disturbs the homeostasis of the knee joint. Understanding the normal structural organization and functional homeostatic limits is necessary to predict the disease of knee joint.

Key Words: Anatomy and Physiology, Knee joint, Femorotibial articulation, Patella and femur

INTRODUCTION

The knee joint is a largest, complex synovial joint of a modified hinge variety. There are three articulations in the knee joint i.e. two between the tibial and femoral condyles and the third with the patella and femur. There is no articulating surface on the fibula to contribute in the formation of the knee joint. Knee is one of the most unprotected joint and it is subjected to all types of acute and chronic injuries leading to pain and disability.

Traumatic injuries of the knee joint can occur anytime during walking, or during sports or road traffic accidents. In a 10 years study 17,397 patients were found to have 19,530 sport injuries it was found that 68.1% of those patients were men and 31.6% were women; and the age of 50% of the patients ranged between 20-29 years (43.1%) at the time of injury[1]. Global adolescent knee injury prevalence ranges between 10% to 25% and in more recent studies it is reported with even higher percentages [2,3].

The principle intra-articular structures in knee are two cruciate ligaments, two menisci and synovium lining the fat pad. They perform functions to maintain the coherence of the knee and any injury therefore; need to be assessed for the proper functioning of these structures. The injury to these intraarticular structures is generally termed as 'internal derangement of knee [4]. Such knee injuries are assessed by the clinical examination, stability tests and radiographic methods with about 70% accuracy [5]. However thorough physical examination of a recently injured knee with hemarthrosis it is often difficult because of pain, swelling and guarding. The various imaging techniques currently used to evaluate pathological status of the knee include radiography, ultrasonography, nuclear medicine, computed tomography (CT Scans) and magnetic resonance imaging (MRI). Radiography is the initial screening modality, it has limited role in the diagnosis of internal derangement of knee, subtle fractures and bone contusions. Computed axial tomography is used for evaluation of complex fractures, however it has limited role in the evaluation of internal derangement. Recently, CT arthrography is being evaluated for its role in intra-articular pathologies [6].

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The interaction of physical and biochemical structures of cartilage is necessary to allow the normal function of providing nearly frictionless motion, wear resistance, joint congruence, and transmission of load to subchondral bone. Chondrocytes are responsible for synthesizing and maintaining the material required for this purpose. Osteoarthritis occurs when there is disruption of normal cartilage structure and homeostasis [7]. Osteoarthritis results from a complex interaction of biochemical and biomechanical factors that occur concurrently to perpetuate degenerative changes. The progressive pathologic change that occurs in osteoarthritis has been characterized, not only for articular cartilage but also for periarticular tissues.

Anatomic organization and stabilizing factors of the knee Joint

The articulating surfaces of the knee joint are contributed by the lower end of femur, superior surfaces of the tibia and patellar posterior surface [8] (Figure 1).

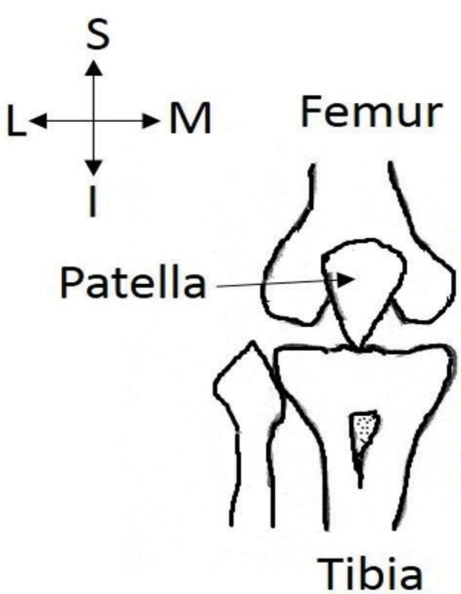

Figure 1: Bones involved in formation the knee.

The intercondylar notch of femur and intercondylar eminence of tibia provides bony stability to the joint much similar to horse rider straddling on back of the horse [9].

The extensor compartment muscle, the quadriceps femoris provides a greater mechanical advantage for the extension. The medial stabilizer is semimembranosus muscle with its five extensions at insertion. During flexion, the semimembranosus and its attachment to medial meniscus pulls the meniscus posteriorly so as to prevent the crushing of meniscus between medial condyles of tibia and femur [10].

Posterior cruciate ligament (PCL) is part of medial tibiofemoral joint and acts like a major stabilizer of knee joint. It is made up of two parts: antero-lateral and postero-medial. The tension within each cruciate varies with the movements of the knee joint [11]. Iliotibial tract and biceps femoris is the main knee joint stabilizer from lateral side. The insertion of biceps femoris reinforces the posterior 1/3rd of the lateral part of capsule. The posterior third of lateral tibiofemoral joint is supported by "Arcuate complex". This complex is composed of 4 components: fibular collateral ligament, posterior 1/3rd of lateral capsular ligament, popliteal tendon and arcuate ligament [12]. The anterior cruciate ligament (ACL) is taut during extension and lax during flexion of the knee, this ligament is also a chief stabilizer of the knee joint [13].

The menisci increase stability for femorotibial articulation, distribute axial load, absorb shock and provide lubrication and nutrition to the knee joint [14-16]. The Injuries to the menisci are recognized as a cause of significant musculoskeletal morbidity. The unique and complex structure of menisci makes treatment and repair challenges or the patient, surgeon and physical therapist. Long-term damage may lead to degenerative joint changes such as osteophyte formation, articular cartilage degeneration, joint space narrowing, and symptomatic osteoarthritis (OA) [17-19]. Preservation of the menisci depends on maintaining their distinctive composition and organization.

Early in embryonic life, the normal menisci develop within the limb bud from mesoderm. They are well defined at 8th week of gestation and by 14th week they gain appropriate anatomical shape [20] and lack a discoid shape [21] the peripheral blood supply recedes during this maturity. By the 9th month of development, the inner third becomes avascular, finally at 10 years of age only the peripheral third has its blood supply [22] and the inner two-thirds receive nourishment via diffusion from the synovial fluid.

In adults' medial meniscus covers 50% of the medial tibial plateau whereas the lateral meniscus covers 70% of the lateral tibial plateau The average width of medial meniscus is 11mm and 6mm high whereas lateral meniscus is 12mm and 4 mm [23] Thus, the average excursion of the meniscus during flexion and extension is greater laterally (10 mm vs. 2.5 mm), a feature that protects against the incidence of lateral menisci tear [24].This helps the convex femoral surface and the flat tibial surface like cushions for the tibial plateau and femoral condyles, respectively (Figure 2).

The menisci serve as shock absorbers and load distributors and play a role in joint stability as well as in synovial fluid distribution and cartilage nutrition. Partial meniscectomy of normal shaped menisci was shown to increase the contact stresses in proportion to the amount of removed meniscus. Following total meniscectomy, the contact area was decreased by 75% while contact stresses increased by 23% [25]. Comparison of thickness and width of various studies is shown in the Table 1.

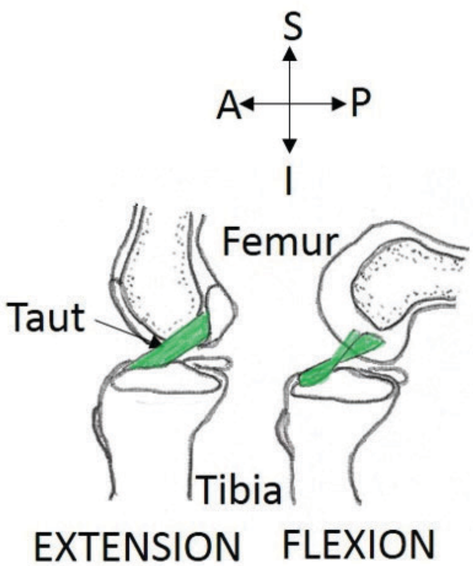

Figure 2: Menisci of the knee joint.

Table 1: Comparison of thickness and width of menisci in various studies [26-34]

Authors (years)	Thickness (in mm.) Lateral meniscus	Thickness (in mm.) Medial meniscus	Width (in mm.) Lateral meniscus	Width (in mm.) Medial meniscus
Testut et al (1975)[26]	8	6	-	-
Hayashi et al (1988) [27]	Average 6-8		Average 12-13	
Filho et al (1999) [28]	12	5	-	
Almeida et al (2004) [29]	5.31	6.10	12.16	11.97
Braz et al (2010) [30]	6.31	6.52	9.32	11.16
Panigrahi et al (2013) [31]	1.4	2.3	3.16	4.61
Ashwini et al (2013) [32]	1.77	1.76	11.28	9.36
Nimje et al (2014) [33]	5	6	9	9
Rao et al (2014) [34]	5.47	5.53	10.6	9.9

Structural Assessment of Knee joint

There are several methods of structural assessment of knee joint in health and disease. Among that the direct examination is the most ideal method but it is practically possible only on cadavers or during the knee surgeries. Apart from that the Joint X-rays, the MRIs are the most common methods [35].

Radiographs of the knee joint can be done in three views like merchant's view, antero-posterior and lateral view. The anteroposterior view is generally easiest to understand as it looks like the skeleton we are familiar with. The kneecap is difficult to see in this view as it overlaps the thigh bone and produces a faint outline. The x-ray of the knee joint with anteroposterior view is used for investigation of arthritis and the region affected like intra-articular or extra-articular. The lateral view is used for diagnosis of arthritis between the femur and patella. The skyline view looks between the kneecap and the thigh bone. It is taken with the knee bent (about 30 degrees) and is used to diagnose arthritis. It is much less common. Only about 30% of orthopaedic surgeons use this view during a routine examination. Radiograph of knee that had no OA features in the patellofemoral compartment were classed as *OA absent*. All the X-rays that had any of the features representing Kellgren and Lawrence grade 1 or above in the patellofemoral compartments were classed as "OA present" [36]. Once all the grading had been obtained, the data needs to be analysed by comparing the readings of the skyline and lateral views as well as the presence of patello-femoral crepitus individually against the operative findings. Kellgren and Lawrence Grading system- grade 0: no radiographic features of OA are present, grade 1: doubtful joint space narrowing (JSN) and possible osteophytic lipping, grade 2: definite osteophytes and possible JSN on anteroposterior weight-bearing radiograph, grade 3: multiple osteophytes, definite JSN, sclerosis, possible bony deformity, grade 4: large osteophytes, marked JSN, severe sclerosis and definite bony deformity). In patients who reported with chronic knee pain a tunnel view is used. It is necessary to find out the presence of knee osteoarthritis [37-38].

The role of MRI in imaging of knee has steadily increased over years. The development of newer sequences, improved signal to noise ratio, higher resolution, shorter imaging times, reduced artefacts and improved accuracy has changed the traditional algorithm for work up of internal derangement of knee joint. Fast spin echo and fat suppression MRI is best for the review of the structure of the ligaments, fibro-cartilage and articular cartilage. MRI is also used to detect bone contusions, marrow changes and tibial plateau fractures. Hence it has become the best modality for pre operative planning of knee joint injuries. MRI has made it possible to look into the injured knee joint non-invasively [39].

Another advanced modality in the management of internal derangement of knee is arthroscopy; it is a minimally invasive surgical procedure in which a fiberoptic endoscope is inserted into the joint through a small incision. The surgeon makes a second incision through which to insert surgical instruments that can be used to debride or resect areas within the knee under visualization through the arthroscope. A variety of treatments can be delivered by arthroscopy, and different elements of treatment might well determine the efficacy

of the arthroscopy in osteoarthritis. Arthroscopy can be used as a dual mode either as a diagnostic or therapeutic tool [40].

Knee Physiology

Knee has the largest and most complex joint structure. It carries load when the person is standing stationary as well as during movement. Understanding the factors which stabilize the joint during standing and movements in health and disease is a huge challenge. Few main concepts and their role in the health like maintaining stability and mobility is described along with its disturbance in most common disease like osteoarthritis. How important is gait of a person! In maintenance of health and development of disease is what is reviewed further.

There are several factors which affect the stability and mobility of the knee Joint. They can be broadly divided into external and internal factors.

The external joint factors which govern the mobility and stability are line and centre of gravity, size and number of base of support and body weight [41]

Line and centre of gravity:Standing on two legs with narrow base is the unique feature of the few mammals. This erect posture enables the human beings to use their forelimbs for exploring the world and thus suitable for working, learning and procreation. Movement through two limbs was possible due to complex arrangements of different types of joints at trunk, hip, knee and ankle. The architecture is such that during standing the body parts should align themselves to fall in the line of gravity. Same principle is also applicable while moving, where there is a dynamic arrangement of the structures of the knee and other parts. For example, fall in the forward direction is prevented by posterior spine muscle contraction, hip extension and knee flexion [42-45].

This is achieved by change in the tone of muscle at appropriate time. In humans on standing posture, the centre of gravity is marked on the anterior part of sacrum. The centre of gravity changes according to the posture of the individual: When the person sits, the distance between the ground and centre of gravity reduces and this increases stability. Stability is achieved when the imaginary line from the centre of the gravity falls at the centre of distance between the two limbs at the ground [46].

Size and number of base of support: In order to increase the stability, the base needs to be increased. This can be made by placing the feet in a certain position. More stability can be achieved by using other body parts, as when an athlete assumes a four-point stance. In people with injured limbs as well as older individuals, support can be achieved by using the cane or crutch. Another way of maintaining the balance is by using the length of foot, stability is achieved by leaning forward and backward. This is achieved by change in tone of muscles according to body requirement [47]. In another study it is reported that, the stability maintained through preferred limb is different from non-preferred limb [48].

Body weight: The body weight contributes to stability. The objects with more weight are harder to move and thus more stable and vice versa [49]. During pregnancy, the female body experiences structural changes, such as weight gain. As pregnancy advances, most of the additional mass is concentrated interiorly on the lower trunk [50]. In such conditions increase in the load with the increase in joint movements increases stress on the musculoskeletal system and contribute to pain [51].

Stability and mobility is mainly due to the frictional resistance at the foot and ground. A young basketball player trying out the new shoes on a freshly polished gymnasium floor would encounter relatively high friction that would improve the stability.

In a study reported by Roszlin et al, the required coefficient of friction (RCOF) was analyzed. The differences in the friction among the flooring types was assessed and found that there were gender differences during the heel contact phase in barefoot gait [52]. The elderly patients tend to fall due to frequent slips because of lower friction, low heel velocity, shorter slip distances. But there is higher hamstring activation rate in young people and the heel contact velocity is less during the gait cycle, particularly during the heel contact phase which makes them more stable [53-55].

More stability is possible with increased body weight but with lesser mobility. Other factors for higher stability are lower centre of gravity, increased friction at the ground contact.

The internal joint factors which govern the mobility and stability:

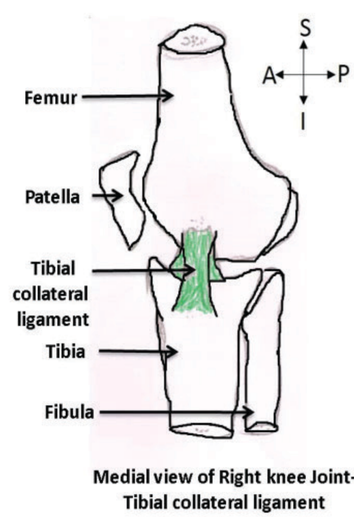

Figure 3: Tibial/Medial collateral ligament of knee joint.

The shape of the condyles and menisci in combination with passive supporting structures gives stability of the knee joint. The passive supporting structures are mainly four ligaments. They are Medial/Tibial Collateral Ligament (MCL), Lateral/ Fibular Collateral Ligament (LCL), Anterior Cruciate Ligament (ACL) and Posterior Cruciate Ligament (PCL).Medial/ Tibial Collateral Ligament connects the femur and tibia, provides stability to the medial aspect of the knee (Figure 3).

Medial and lateral collateral ligaments relax at 20 to 30 degrees of flexion. The MCL and posterior oblique ligament resists abnormal internal rotation of tibia. MCL injury occurs when direct blow occurs on lateral side of semi flexed knee. Further severe blow can cause cruciate ligaments injury [56].

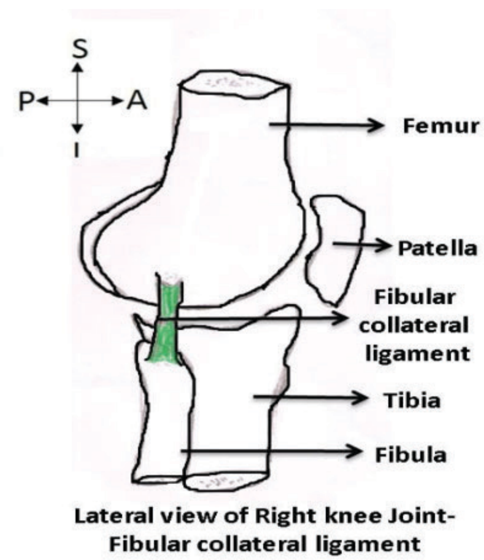

Figure 4: Fibular/Lateral collateral ligament of knee joint

Lateral/Fibular Collateral Ligament provides stability to the lateral side of knee (Figure 4).The static stabilizer to the lateral part of knee joint is LCL, augmented by cruciate ligaments and popliteofibular ligament. The popliteofibular ligament is the primary restraint to posterolateral rotation, augmented by the LCL and the popliteus tendon [57-60]. The posterolateral corner contributes to the stability of the knee. It has a complex structure and makes assessment and surgery difficult. There is considerable variation in the anatomy from person to person [60].

Biomechanical tests for assessing these structures were done, by simulating a pure varus stress on knee. It revealed that the LCL failed first, followed by popliteofibular ligament, and then the popliteal muscle belly. The mean maximal force to failure of the popliteofibular ligament approached 425 N (204 to 778), compared with 750 N (317 to 1203) for the LC [61]. A study done by Yoon et al 2013 on the computational studies: revealed that translational and external rotational stabilities were contributed by the posterolateral corner structures [62].

Anterior Cruciate Ligament (ACL) is in the centre of the knee, limits rotation and forward movement of the tibia. The major role of the ACL is to give stability against anterior tibial translation (ATT). Cutting-edge studies have demonstrated an important role of ACL for ATT and also pivot shift at different flexion angles. In studies done on cadavers, a posterolateral fibres of ACL has a stabilizing role in controlling the ATT at near-to-extension angles and an anteromedial fibre of ACL has a role in controlling higher flexion angles of knee [63-65]. The Anteromedial fibres of ACL is taught during flexion and postero-lateral fibres of the ACL is tighter during extension. This allows different portions of ACL to be taut throughout the range of motion, allowing the ligament to function throughout flexion and extension. The ACL also contains proprioceptive nerve endings [66, 67] (Figure 5).

Posterior Cruciate Ligament (PCL), is also located in the centre of the knee, and like the ACL secondarily limits rotation, while primarily limits backward movement of the Tibia (Figure 6).

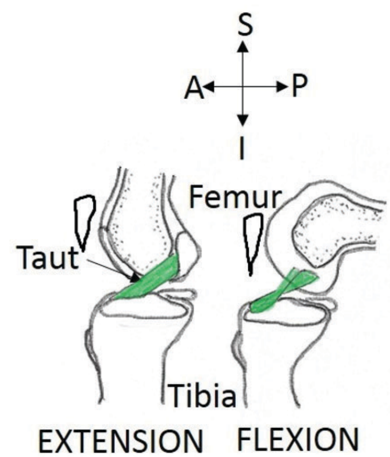

Figure 5: Anterior Cruciate Ligament of Knee joint.

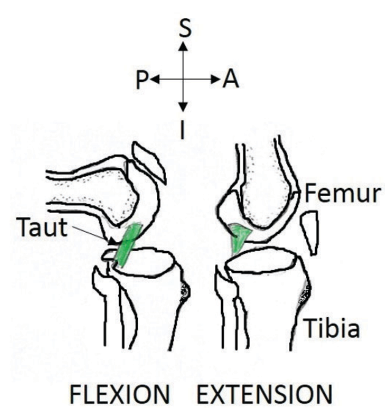

Figure 6: Posterior Cruciate Ligament of Knee joint.

In a study, computer simulation knee model was used and a simulation of squatting activity was done in weight-bearing deep knee flexion. PCL length was changed to represent different PCL tension models as it significantly influences knee kinetics and kinematics [68] (Figure 7).

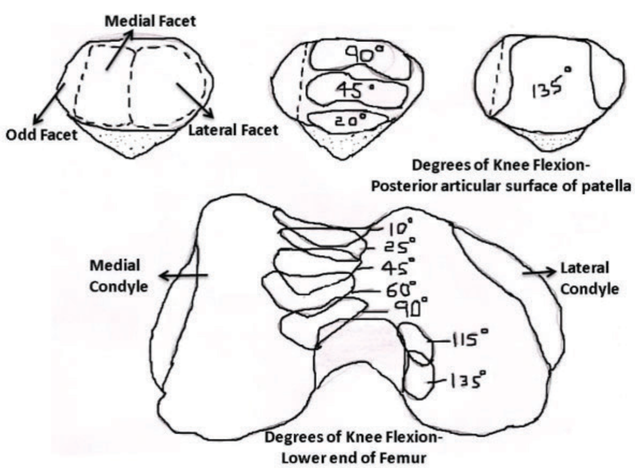

Figure 7: Patellofemoral articulation- varies with the degree of flexion of knee joint.

The knee joint is one of the vulnerable joints which are easily injured. Unlike the hip joint which has a very stable ball-and-socket configuration, the architecture of the knee imparts little support to the joint's stability. This makes the knee ligaments prone to injury with any stretch to the knee, like the force of a hard muscle contraction (e.g. performing a quick change of direction when sprinting) [69-71].

CONCLUSION

The knee is a complex joint with different articulating compartments inside. The ligaments and the tendons attached to it work in coherence in a pattern to support the actions of knee joint. In addition, the support of structures in maintaining the posture is also reviewed. Such review will help us in understanding the specific pathophysiological process for the onset of diseases related to knee joint like osteoarthritis. The literature concerning kinematic and kinetic studies on the knee joint is comprehensively reviewed in this article. The architecture of menisci and investigations to diagnose osteoarthritis and role of healthy gate in prevention of degenerative joint diseases is also elaborated.

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Abbreviations used:

MRI - Magnetic Resonance Imaging
CT- Computed Tomography
FBOS - Functional base of support
RCOF- Required Coefficient Of Friction
MCL- Medial Collateral Ligament
LCL- Lateral Collateral Ligament
ACL- Anterior Cruciate Ligament
PCL- Posterior Cruciate Ligament
ATT- Anterior Tibial Translation
OA- Osteoarthritis

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